REVERSE OSMOSIS APPLICATIONS FOR METAL FINISHING OPERATIONS

The Merit Partnership is a joint venture between the U.S. Environmental Protection Agency (EPA) Region 9, state and local regulatory agencies, private-sector industries, and community representatives that was created to promote pollution prevention (P2), identify P2 technology needs, and accelerate P2 technology transfer within various industries in southern California. One of these industries is metal finishing, which is represented in the Merit Partnership by the Metal Finishing Association of Southern California (MFASC). Together, MFASC, EPA Region 9, and the California Manufacturing Technology Center (CMTC) established the Merit Partnership P2 Project for Metal Finishers. This project involves implementing P2 techniques and technologies at metal finishing facilities in southern California and documenting results. The project is funded by the Environmental Technology Initiative and EPA Region 9.

This fact sheet provides technology transfer information on reverse osmosis (RO) applications for metal finishing operations in general and presents the results of a specific RO application case study conducted at a metal finishing facility in southern California.

WHAT IS REVERSE OSMOSIS?

Reverse osmosis (RO) involves separating water from a solution of dissolved solids by forcing water through a semipermeable membrane. As pressure is applied to the solution, water and other molecules with low molecular weights (less than about 200 grams per mole) pass through micropores in the membrane. Larger molecules, such as organic dyes and metal complexes, are retained by the membrane. The purified stream that passes through the membrane is called permeate, and the concentrated stream containing a high concentration of dissolved solids is called concentrate. RO membrane systems feature cross-flow filtration (illustrated in Figure 1) to allow the concentrate stream to sweep away retained molecules and prevent the membrane surface from clogging, or fouling.

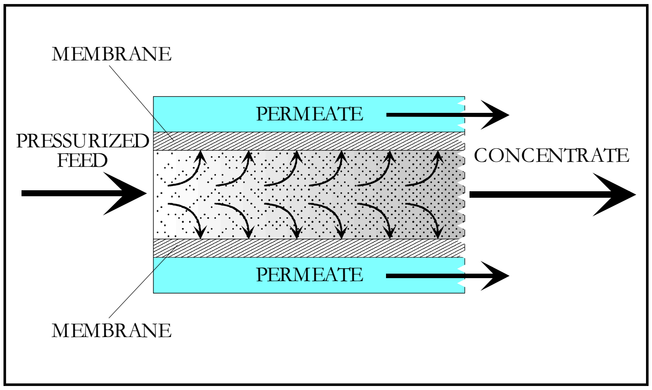

Figure 1. Reverse Osmosis Cross-flow Filtration

> **Contaminant Buildup**
>
> Although "closing the loop" has many advantages, it also has disadvantages: contaminant buildup. Contaminants, such as unwanted metals from preceding process operations, may "enter the loop" as a result of drag-in and slowly accumulate in the closed-loop operation, which may impact the process chemistry. Therefore, bath monitoring is essential to successful use of recycling systems such as RO. Built-up contaminants may also precipitate out of solution and cause membrane fouling.

In the past, RO applications for electroplating operations were mostly limited to final treatment of a combined wastewater stream. Such applications typically involved discharging the permeate to a POTW and returning the concentrate to the head of the wastewater treatment system. Because of the high flow rates associated with treating combined wastewater streams, large, costly RO units were required. More recent metal finishing applications of RO have involved installing RO units in specific process operations, allowing return of the concentrate (recovered chemical solution) to the process bath and reuse of the permeate (cleaned rinse water) as fresh rinse water. By "closing the loop," valuable process chemicals are recovered, and less fresh water is needed. Furthermore, a waste stream is eliminated that would otherwise be discharged to the POTW. RO systems have been successfully applied to a variety of metal finishing operations including several types of copper, nickel, and zinc electroplating; nickel acetate seal; and black dye.

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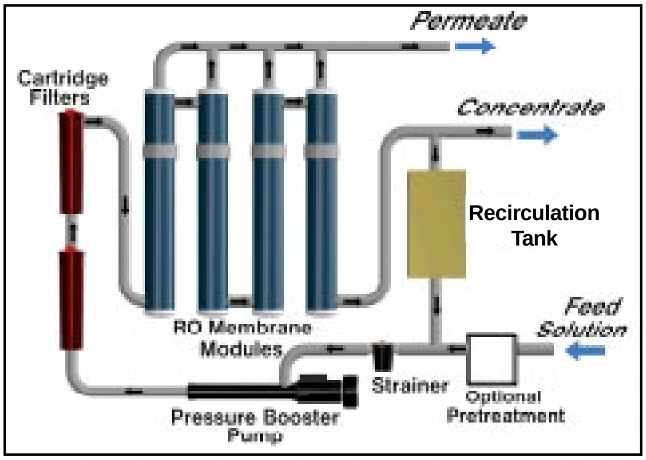

Figure 2. Basic Components of an RO Unit

RO UNIT COMPONENTS

Figure 2 shows a basic RO unit. The essential components include a strainer, a pressure booster pump, cartridge filters, and the RO membrane modules. The strainer removes large, suspended solids from the feed solution to protect the pump. The booster pump increases the pressure of the feed solution; typical operating pressures range from 150 to 800 pounds per square inch (psi). Commercially available cartridge filters are used to remove particulates from the feed solution that would otherwise foul the RO units. Filter pore sizes are typically between 1 and 5 microns.

Membranes are assembled in modules, each of which compacts a membrane of large surface area within a cylindrical shell of small volume. The type of commercially available module most applicable to metal finishing operations is the spiral-wound module. Although a number of membrane materials are under development, two commercially available membrane materials are currently in common use: aromatic polyamides and cellulose acetate. The aromatic polyamide membranes used in spiral-wound modules typically take the form of thin-film composites. Such a membrane consists of a thin film of membrane bonded to layers of other porous materials that support and strengthen the membrane. Thin-film composites can be applied over a relatively broad pH range (2 to 11), can tolerate a maximum temperature of about 115°F, and are more durable than single-material membranes. Cellulose acetate membranes are limited to a fairly narrow pH range (2.5 to 7) and a lower maximum temperature (about 85°F), and such membranes are biologically degradable.

The type of RO membrane and module needed depends on feed solution characteristics and the desired performance of the RO unit. RO vendors or consultants often select an off-the-shelf unit that is most appropriate for a given application. Pilot tests are often necessary before a full-scale RO system is implemented.

Before Implementing RO . . .

Before implementing RO, low-cost P2 techniques and other good operating practices such as process monitoring should be adopted. For example, countercurrent rinsing should be implemented to reduce the required rinse water flow rate. This will reduce the RO feed flow rate, and as a result, smaller, less costly RO units and pretreatment systems can be used.

Pretreatment Considerations

Depending on the feed characteristics, optional pretreatment considerations include:

pH Adjustment: If the feed solution pH is outside the acceptable range for the membrane or near the solubility minimum of the feed solution ions, pH adjustment may be necessary to avoid damaging or fouling the membrane.

Oil and Grease (O&G) Separation: O&G may be present in the feed as a result of drag-in from other processes. If the feed contains O&G, it should be removed using an oil-water separator or a coalescer.

Disinfection: Feed should be disinfected to prevent bacteria from building up and fouling the membrane; ultraviolet (UV) light is preferable to chlorine to avoid a subsequent dechlorination step.

Temperature Adjustment: If the feed solution temperature is greater than the maximum allowable temperature for the membrane, heat exchangers or other devices can be used to cool the feed solution and prevent membrane damage.

RO UNIT OPERATION AND MAINTENANCE

RO unit operation involves adjusting valve and pump settings to control the pressure and flow rates of the feed and concentrate streams. The most significant RO maintenance requirement is membrane cleaning or replacement as a result of fouling. Membrane fouling results from poor feed solution characteristics, which are controlled largely by some of the pretreatment steps discussed above. When fouling is prevented or minimized by effective pretreatment, RO unit maintenance requirements are minimal. For example, cartridge filters may require periodic maintenance or replacement.

COST CONSIDERATIONS

The **capital and installation cost** for an RO unit is highly application specific. However, as illustrated by the Danco Metal Surfacing (Danco) case study, an RO unit used for an electroplating application involving low influent flow rates (3 to 5 gallons per minute [gpm]) and little pretreatment can cost $10,000 or less. This basic cost covers the strainer, pressure booster pump, cartridge filters, RO membrane modules, plumbing, and installation. The capital cost of an RO system is also impacted by the amount of pretreatment required. Many RO units are compact and have low space requirements (the Danco unit needs only 6 square feet [ft^2]), which reduces installation costs. **Operation and maintenance (O&M) costs** associated with RO units are relatively low. Energy costs are typically low because the only energy needed is for pumping. However, energy costs increase if UV disinfection and temperature adjustment are required. Because RO units are automated, little operator attention is required and labor costs are typically low. Maintenance costs are driven by membrane cleaning and replacement schedules, which are determined by influent characteristics and pretreatment effectiveness.

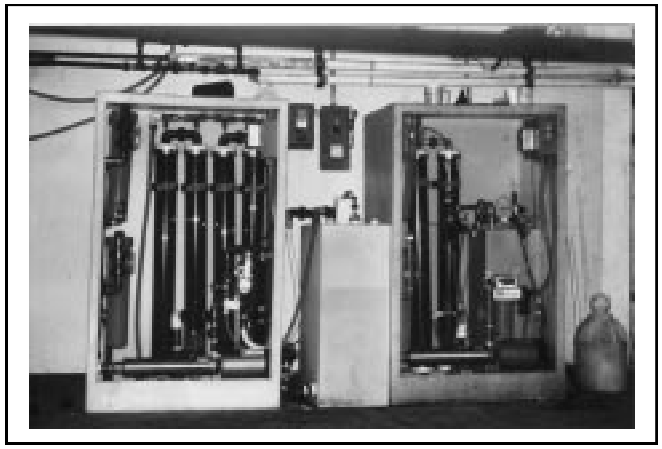

Figure 4. Ecosystems RO Units Installed at Danco

RO APPLICATION CASE STUDY: DANCO AND ECOSYSTEMS

The Merit Partnership sponsored a P2 project involving RO at the Danco facility in Ontario, California. The main objective of the Danco P2 project was to assess the impact of applying RO to metal finishing operations. The 10,000-ft^2 Danco facility has about 30 employees and operates two shifts per day. Danco anodizes small- to medium-sized parts such as screws, flashlight parts, and bicycle frames. Facility anodizing operations include cleaning, etching, anodizing (sulfuric acid-based), chromate conversion, several types of dying, and nickel acetate and hot water sealing. An RO unit developed by Ecosystems of Costa Mesa, California, was installed in the nickel acetate sealing operation in June 1994, and another Ecosystems RO unit was installed in the black dye operation in August 1995. These units feature closed-loop configurations that return reclaimed rinse water (permeate) to the rinse baths and return concentrated process chemicals (concentrate) to the process baths. Figure 3 shows the layout of the RO units installed in the nickel acetate and black dye operations, and Figure 4 is a photograph of these RO units.

When the RO units were installed, Danco replaced its single-stage rinses with two-stage, counterflow rinses to reduce the rinse water flow rates needed for effective rinsing. In each operation, the rinse water that overflows the first-stage rinse tank is pressurized by a high-pressure feed pump. Particulates are removed from the feed solution by two 1-micron cartridge filters. The feed solution then flows in series through spiral-wound modules containing thin-film composite RO membranes (two modules for nickel acetate and four modules for black dye operations). After separation, the portion of the concentrate stream needed to maintain the correct level in the process bath is returned to the process bath in order to recover valuable chemicals. The remaining portion of the concentrate stream is conveyed to the recirculation tank, where it is temporarily stored before being recirculated through the RO unit. Permeate is conveyed to the second rinse tank and is reused as clean rinse water. A small amount of fresh deionized water from an outside source is added to the process baths in order to make up for evaporative water losses. Table 1, on the following page, shows the specifications of the black dye RO unit.

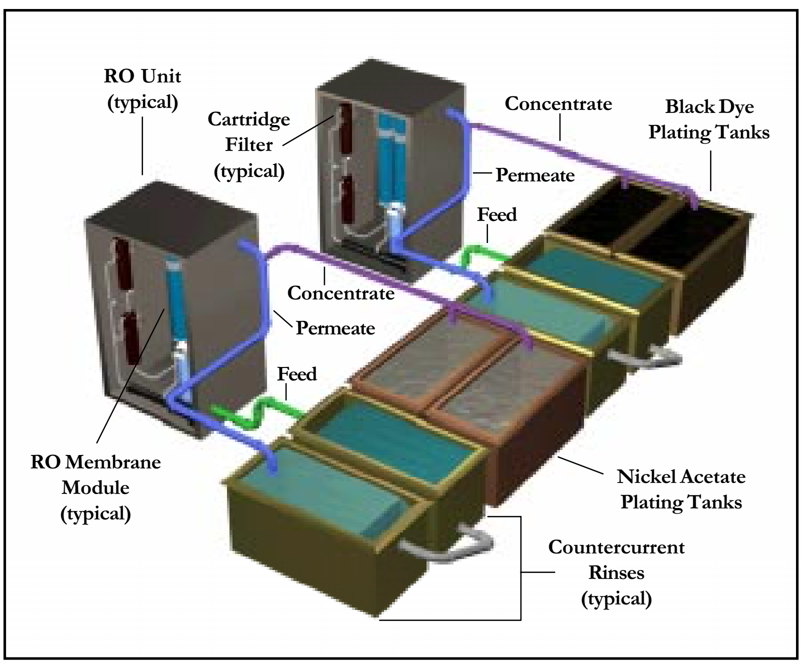

Figure 3. Danco Black Dye and Nickel Acetate Operations Configuration after RO Installation

Feed pretreatment required by the nickel acetate RO unit includes UV disinfection. The black dye RO unit does not require feed disinfection because the black dye inhibits microorganism growth. After a few months of RO unit operation, O&G in the black dye rinse water caused fouling of the RO membranes. Danco and Ecosystems eliminated this problem by changing the location of the feed solution intake from the surface of the rinse tank (where O&G floats) to the center of the tank.

Table 1 Specifications of Ecosystems Black Dye RO Unit	
Unit Size:	Footprint: 2 ft by 3 ft, Height: 5 ft
Power:	3 Phase, 110/240 VAC, 3 HP
Feed Rate:	3 gpm
Operating Pressure:	150 to 180 psi
pH Range:	4 to 8
Max. Temperature:	115°F

Impacts of the Black Dye RO Unit at Danco

Because limited data are available on the nickel acetate operation before RO unit installation, the performance of the black dye RO unit is featured in this case study. Figure 5 shows that the black dye use rate decreased significantly after installation of the RO unit. **These results are particularly noteworthy considering that Danco's production rate increased by about 50 percent 2 months before the RO unit was installed.** Table 2 summarizes the material purchase and waste disposal reductions and savings; savings include black dye and city water costs and waste water discharge fees. The black dye solution contains about 300 parts per million trivalent chromium (Cr^{+3}). Before the RO unit was installed, black dye rinse water containing Cr^{+3} was discharged to the local POTW for treatment. This Cr^{+3} containing wastewater stream was eliminated as a result of RO unit installation.

Contaminants in the black dye rinse water (RO feed solution), such as chloride, sulfate, and metals, may slowly accumulate in the process bath as they are retained by the RO membrane and recycled to the process bath in the concentrate. Danco personnel report no adverse impacts on the quality of finished parts since the installation of the RO unit. In addition, at another Danco facility where RO has been used in a similar black dye operation for over a year, Danco personnel observed no adverse impacts on process quality.

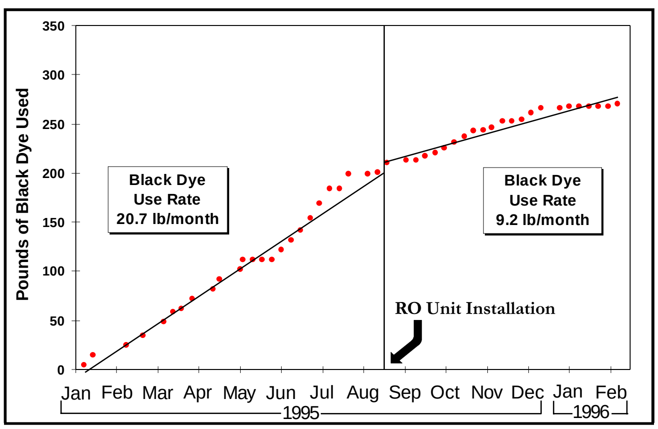

Figure 5. Cumulative Black Dye Use

Table 2
Black Dye RO Unit Results

	Before	After	Monthly Savings
Black Dye Use	20.7 lb/mo.	9.2 lb/mo.	$293
City Water Use	3 gpm	0 gpm	$ 83
Wastewater Discharge	3 gpm	0 gpm	$133

Annual Savings: $6,111
Payback Period: about 2 years

Anecdotal information regarding the nickel acetate RO unit indicates similar performance in terms of raw material use reduction, cost savings, and no adverse impacts on process quality.

Black Dye RO Unit Costs

Cost information was obtained from Ecosystems invoices, Danco utility bills, and other information obtained from Ecosystems and Danco. The capital and installation cost for the black dye unit was $10,000. O&M costs include power, membrane cleaning, and cartridge filter replacement. Power costs are estimated to be about $105 per month, based on Danco's current production schedule (three 8-hour shifts, 5 days per week.) The membrane requires periodic cleaning; however, according to Danco, cleaning costs (supplies and labor) are negligible. Cartridge filters are replaced every 2 to 4 weeks at an average cost of $12 per month. The life of the RO membrane in the black dye unit is unknown; therefore, potential membrane replacement costs were not included in the payback period calculation. Also, the payback period calculation did not include RO unit depreciation.

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